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OBJECTIVITY IN THE CLASSIFICATION OF NORTH AMERICAN WEATHER TYPES

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Edmund T. Clark

OBJECTIVITY IN THE CLASSIFICATION OF NORTH AMERICAN WEATHER TYPES

by

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Lieutenant Commander, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

IN

METEOROLOGY

United States Naval Postgraduate School
Monterey, California

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~~Thesis~~

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ABSTRACT

An objective method of classifying the Elliott North American surface weather types is attempted; a dictionary of weather types is presented with each type defined in terms of seven synoptic parameters. These parameters are as follows: the 500-mb flow pattern, the 500-mb ridge location, the existence of a surface Great Basin Anticyclone, the existence of a surface Great Basin Anticyclone 24 hours ago, the existence of a surface Mackenzie River Anticyclone, the latitude of the 105th meridian crossing of the trajectory of cyclone centers and the existence of an area of relatively high pressure southwest of California. Thus, the classification is based on predominant recognizable flow features at the 500-mb level and the spacial and temporal features of the surface map. The method is capable of machine coding and presents a logical approach to rapid identification of a particular weather type in the North American west coast region.

The writer wishes to express his appreciation for the assistance and encouragement given him by Professor William D. Duthie of the U. S. Naval Postgraduate School in this investigation. Further appreciation is expressed to Captain Lewis L. Mills, U. S. Marine Corps, fellow student, for his constant co-operation and instructive criticism during many hours of weather typing.

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1. Introduction

The history of weather classification prior to 1940 as well as some practical applications of objective methods of forecasting are contained in a 1947 paper by Vernon [18]. It remained for Krick [9] and Elliott [5] to publish a weather forecasting technique utilizing weather types capable of effective use in the preparation of both short- and long-range forecasts. The results of their investigation indicated eleven basic types of surface weather patterns occurred frequently enough and with sufficient uniqueness to portray most North American weather situations. The eastern lobe of the Pacific Anticyclone, the Aleutian Low, the trajectory of polar outbreaks and the direction of motion of migratory storm centers were the parameters used to define each particular type. Elliott [6, 7] and Ruch et al [14] continued to work with weather typing in an attempt to improve classification and prognostication.

Elliott [6, 7] advocated a three-day lifetime for each type based on the passage of one cyclone family across a "region." He further indicated a preferred upper-air (700-mb) flow pattern for each type. It was found that for classification purposes the weather of a region generally could be divided into two distinct classes according to this flow pattern, that is, meridional or zonal.

The meridional flow class is characterized by large amplitude, upper-level trough-ridge systems which steer migratory sea-level pressure centers abnormally far north or south of their average track. Polar outbreaks penetrating far to the south are frequent with this class.

The zonal flow class is characterized by relatively flat westerly flow. The types within this class are distinguished by the latitude of the westerly wind belt.

A brief description of Elliott's North American weather types may

help to understand the problem of describing them objectively. Figures 1 and 2, taken from [6], show the higher pressure regions as stippled, the polar outbreaks as double arrows, the upper-air flow in dashed arrows and the successive 24-hour positions of typical cyclones.

Elliott separates the upper-air flow classes into types as follows. The meridional patterns (figure 1) are types Bn-a, Bn-b, Bn-c, A, D, C_l and C_h; the zonal patterns (figure 2) are types B, B_s, E_l, E_m and E_h. Subsequent unpublished work by Elliott [8] contains a few more classifications modifying existing types in accordance with anomalies peculiar to California. These modifications are not considered in this investigation inasmuch as further separation of synoptic features into particular type determinations is thought to be unnecessarily complicating.

Types Bn-a and Bn-b have similar patterns with respect to the location of their upper-level ridges and troughs. The amplitude of the upper wave is the major difference. Each has a strong, persistent, sea level Great Basin Anticyclone which diverts migratory storm centers, moving eastward from the quasi-permanent Gulf of Alaska Low, northward as they enter the North American continent. The fronts associated with type Bn-a are weak. A type Bn-b low pressure center, in accordance with the deeper upper-level trough, is steered more to the south as it enters central Canada. As cold air penetrates to far-southerly latitudes, frontal waves are frequently generated in the eastern Gulf of Mexico or along the east coast. The main upper-air ridge is located about 115-120°W and the associated trough at 90°W.

Type Bn-c has its trough-ridge systems located approximately 10 to 15° farther westward than those of the previous types; the eastern trough is much deeper. The sea-level Great Basin Anticyclone is considerably weaker and merges to the west with the Pacific Anticyclone, but, if present, it

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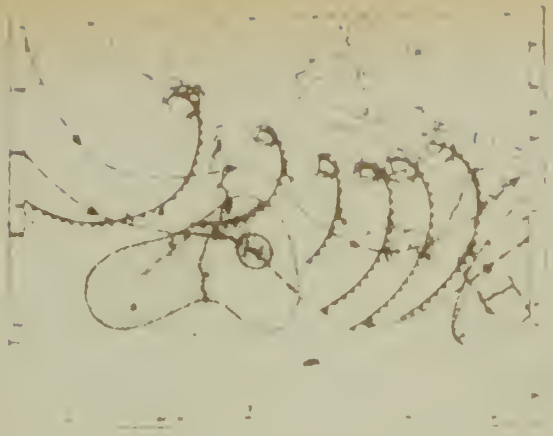

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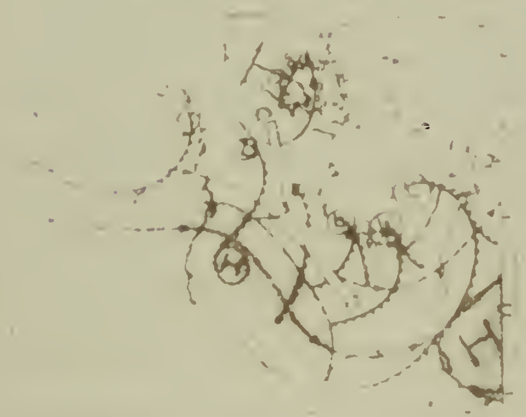

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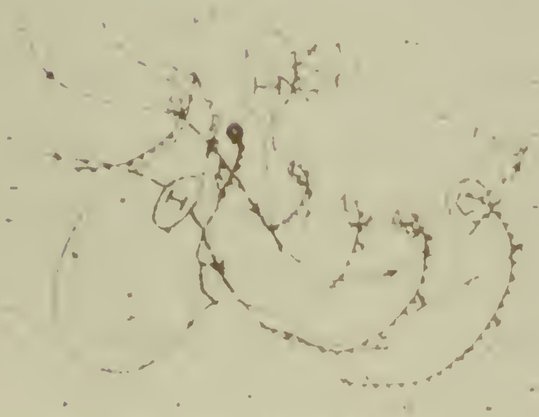

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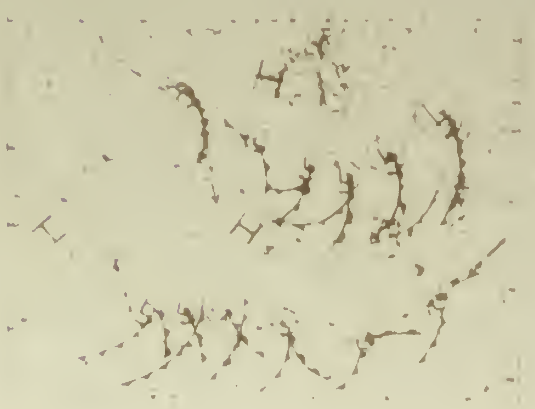

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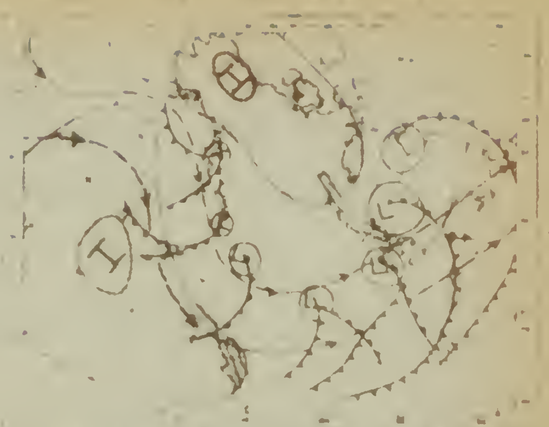

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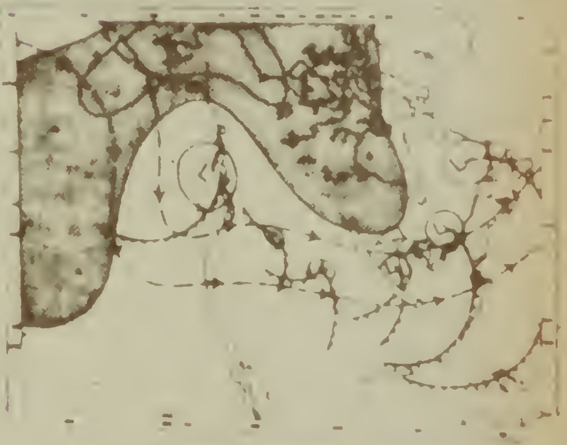

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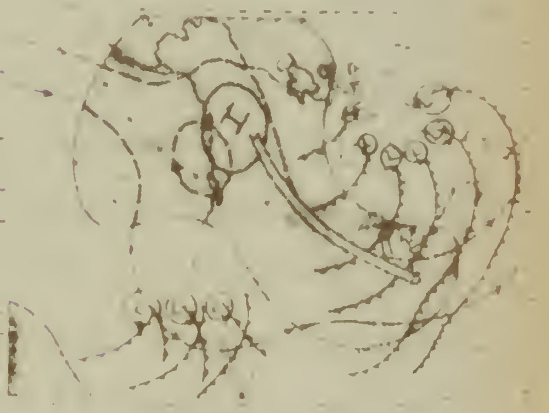


TYPICAL NORTH AMERICAN TYPES

after Elliott

Figure 1

is persistent. The resulting high-pressure belt shelters the west coast of the United States from migratory storm centers which are now steered through British Columbia. As the centers enter central Canada they plunge southward and deepen in the region of the upper-level trough. Another major low center deepens in Colorado. The upper-level ridge is at 135°W and the trough is at 100°W.

A further westward shift of the upper-level trough position is evident in type A. The Great Basin Anticyclone has disappeared in favor of the unusually strong and far-northerly displaced eastern lobe of the Pacific Anticyclone. Surface waves which form along the southeast Alaskan or British Columbian coast are steered rapidly down the coast through Washington and Oregon into the Great Basin area. As cyclones move eastward across the Rockies, further intensification occurs. The deepened center then moves northeastward across the Great Lakes into Canada. The upper-level ridge is located at 145-150°W, and the trough is at 105-115°W.

Type D is the extreme meridional type with the principal trough off the West Coast. At the surface the eastern lobe of the Pacific Anticyclone has an unusual "horseshoe" shape, extending from its normal position northward, apparently merging with the Alaskan cold polar continental High. As the frontal systems move eastward from a quasi-permanent low center off the British Columbia coast, new wave centers develop in Montana and are steered through central and northeastern United States. The principal outbreak of cold air occurs so far to the west that a minor cold outbreak is found to the rear of the secondary trough along the east coast. The upper-level ridge is found at 160°W and the trough at about 130-135°W.

The final two meridional types are so similar they differ only by the intensity of the polar outbreak. These are the C types, C_l and C_h, characterized by an abnormally displaced Great Basin High with center in

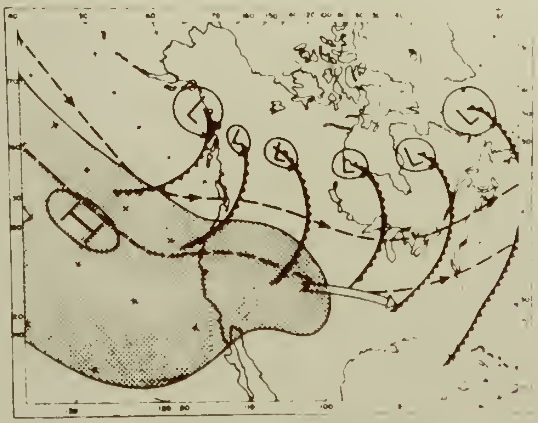
British Columbia. This is associated with a split or block in the upper-level westerly wind belt resulting in two storm tracks over western North America which later converge downstream. The northern branch moves along a crest at about 125°W while the southern branch moves along a trough at this same longitude. As the high-pressure cells migrate eastward others immediately develop over the northern Great Basin to replace them. Polar outbreaks, principally with the C_h types, are most pronounced in the Great Plains states. As the storm centers move eastward along the southern path, their motion is very erratic, and they often appear on the weather map as several closely-spaced waves. The upper ridges and troughs are located at 125-130°W and 70-85°W, respectively.

The zonal types (figure 2) are characterized by predominantly zonal flow in or just to the west of the region of consideration.

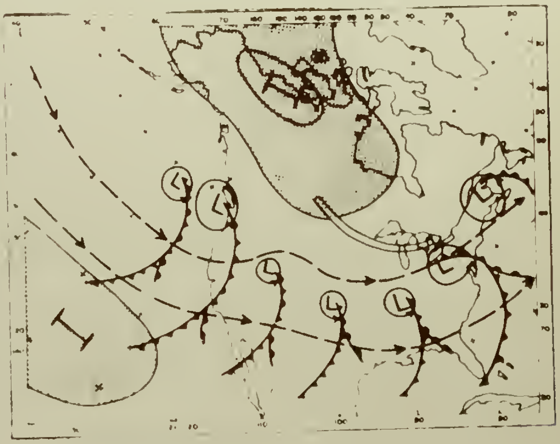
The first zonal type, B, is distinguished by a belt of distinct subtropical anticyclones across the Unites States with a storm track well to the north. The upper-level flow is almost straight west-to-east except for minor troughs off each coast of the United States. The migratory storm centers which move eastward from the Gulf of Alaska through northern Canada have weak frontal systems which trail southward from the center into the United States. No strong polar outbreaks occur in the United States with this type. The trajectory of the low centers over the Rockies (105°W) is north of 55°N latitude.

Type B_s is very similar to the Bn-a of the meridional category except that the eastern upper-level trough is deeper and the western upper-level ridge is weaker. A small portion of the Gulf of Alaska Low breaks off as a frontal system and moves eastward across the Rockies, intensifying to the north of the Great Lakes. Another low-pressure center often follows within two days. The trajectory of the low centers is between 50 and 55°N

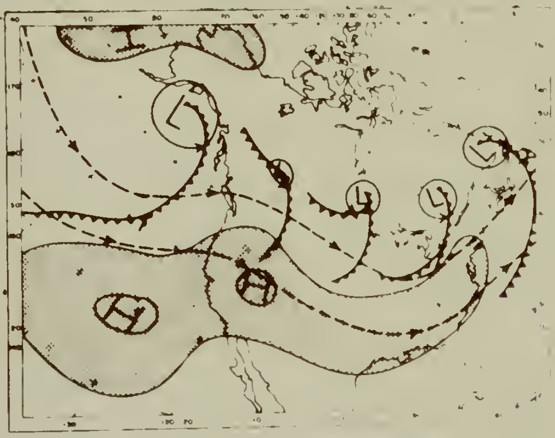
TYPE B OF NORTH AMERICAN WEATHER TYPES



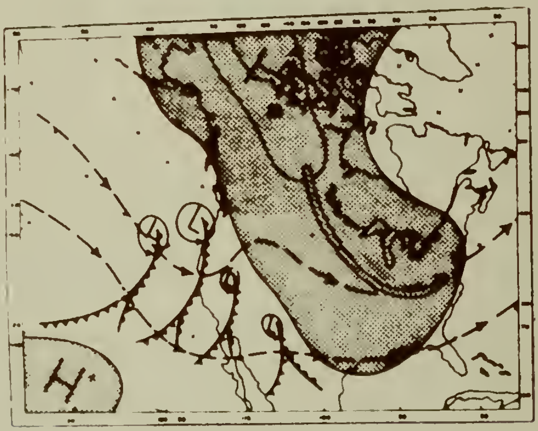
TYPE E_N OF NORTH AMERICAN WEATHER TYPES



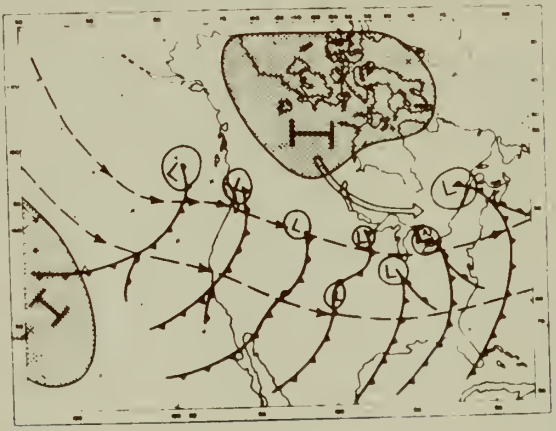
TYPE B_s OF NORTH AMERICAN WEATHER TYPES



TYPE E_H OF NORTH AMERICAN WEATHER TYPES



TYPE E_c OF NORTH AMERICAN WEATHER TYPES



ZONAL NORTH AMERICAN TYPES

after Elliott

Figure 2

at 105°W.

Type E_l continues the southerly movement of the trajectories of the low centers across 105°W by crossing at about 47°N. A weak but persistent cold continental high-pressure cell stagnates in northern Canada and Alaska. Storm centers enter western North America near the 50th parallel and dip slightly southward as they cross the Rockies. A new wave often develops along the frontal zone just east of the Rockies. This becomes a major storm and then travels northeastward across the eastern part of North America. At times when the air north of the storm track is exceptionally cold, the increased temperature gradient and wind field cause the low centers to move much more rapidly than indicated on the map. In fact, the movement is so rapid that there is no time for waves to develop on the frontal systems.

In type E_m the upper-level westerlies (over an area from the mid-Pacific to the U. S. Atlantic coast) are displaced considerably farther south than normal (crossing 105°W about 40°N) and a large persistent sea-level high pressure center is located in Alaska and northwest Canada. Cyclones approaching the west coast reach their maximum intensity just offshore at 45-50°N. As the frontal zone moves, a new cyclonic center develops in the Great Basin. This storm moves east-southeastward, being continually pressed southward by the cold polar air to the north until it reaches the Appalachians where it deepens rapidly and begins to move northward.

Type E_h is characterized by an extreme low latitude position of the upper westerlies with low centers on the surface crossing 105°W at 34°N. An exceptionally strong surface High is centered in Alaska and northwest Canada and extends southeastward over most of the North American continent. This High completely dominates the weather over the United States, forcing storms which enter the west coast at low latitudes to move southward

around the southern periphery of the High. These storms usually weaken and disappear from the surface weather map before reaching the Gulf of Mexico.

Inasmuch as all E types are marked by the extreme southerly position of the westerlies aloft, they are indicative of a return of the westerlies to more northerly latitudes and thus are unstable. These types should not be forecast to exist for more than three days without strong basis for so doing.

2. Investigation

If there does exist an upper-air flow pattern associated in a unique way with a particular surface synoptic situation, then this dual determination would lead to a three-dimensional classification of weather types. Elliott [6, 7, 8] has already indicated a preferred 700-mb flow pattern (figures 1 and 2). Baur [2] has similarly indicated a 500-mb flow pattern for his eight European weather types. Thus, if the 700-mb patterns for Elliott's types were re-oriented for 500 mb, the latter may be applicable for dual determination.

Assuming there does exist a peculiar upper-air flow pattern for recognizable and unique surface weather situations, there should exist corresponding relative topography patterns. Accordingly, the first line of investigation led to a review of the investigation of Sutcliffe and Forsdyke [16]. Possible thermal vorticity applications required the computation of a relative divergence field which, while possibly being a definitive parameter, proved too extensive a project for the purpose of a simple objective technique capable of use by any meteorological station. This line of inquiry was abandoned.

The 1000/500-mb thickness patterns of several representative samples of Elliott's weather types were examined and compared. The same months of various years were selected to minimize seasonal differences. No observable uniqueness or similarity peculiar to any type was noticed.

A second consideration of upper-air flow was the possible application of distinguishing features of the jet stream. Excessive variations in wind profiles within individual types appeared to render the application of wind profiles impractical. A detailed analysis code for the location of the jet stream maximum in the 250-mb level ridge-trough system over western North America was evolved to show numerically the relative location, width,

intensity and length of the maximum. When known surface weather types were compared with their corresponding jet-maxima features, no degree of uniqueness could be found.

Serebreny et al [13] and Vederman [17] discuss the relationship of the 500-mb jet stream and maxima to the surface weather in connection with cyclones and frontal systems. The jet-maximum description used above was applied to the 500-mb level long- and short-wave patterns with no discernible uniqueness for any particular surface type.

The above investigations began to indicate that while there was indeed a particular upper-air flow pattern associated with Elliott's surface weather types it may be necessary to describe the entire upper-level surface in order to discern it. Bryson and Kuhn [3] and Senn and Bryson [15] had numerical methods of describing 500-mb flow; however, both contained too broad a description for the area of interest. In addition, both were too complicated for a simple "cook-book" method of classification. On the other hand Cox's [4] map codification system was very well suited to describing the 500-mb pattern in increments of 30° of longitude between latitudes 30°N and 60°N.

Applying Cox's system to representative upper-air (500-mb) charts for the three Bn types gave the flow directions in Table 1. The actual or gradient flow was assigned a number in accordance with the direction from which it came by use of an overlay consisting of eight sectors numbered clockwise with Sector Eight being bisected by North. The predominant flow for each ten degrees of latitude is indicated for central meridians of the three divisions between 90°W and 180°W. "0" and "9" indicate variable flow and curved contours with any intensity or any intensity greater than five knots, respectively. Note the variations in flow but the evident general or broad pattern of each type.

TABLE 1

	165°W	Ave	135°W	Ave	105°W	Ave	
60-50°	99909	○	55556	↗	59779	↘	
50-40°	66656	→	55556	↗	98777	↘	Bn-a
40-30°	77666	→	85557	↗	66606	→	(5 cases)
60-50°	5699	○	6455		0778	↘	
50-40°	9667	→	6555	↓	6677	→	Bn-b
40-30°	6667	→	9699	○	5687	↘	(4 cases)
60-50°	5590699	○	9667577	↘	7777606	↘	
50-40°	5568568	→	7788689	↘	5966766	↓	Bn-c
40-30°	5567578	→	7989989	○	5655756	↗	(7 cases)

In the average flow column zero indicates variable flow while the arrows indicate the dominant flow direction.

When compared to figure 1, the average flow pattern coincides with the 700-mb pattern except for the slightly westward displacement. With this amount of coincidence the 500-mb flow for the other types could be determined from Elliott's 700-mb flow. However, the patterns as described by Cox's method differed slightly from Elliott's patterns in that type B_s seemed to have more meridional than zonal flow. This may be a matter of degree only. Type C could be found under an offshore ridge as well as an overland ridge as long as a trough existed over the southern California region. Further, type Bn-c occurred under split or blocking flow aloft rather than a ridge pattern. In most types the location of the ridge with respect to the 130th meridian seemed significant.

The investigation now turned toward a simpler synoptic-parameter approach in the search for definitive features. This decision to attempt objective classification by broad scale descriptive features followed the realization that while upper-level flow patterns are fairly regular and well-behaved their surface counterparts are influenced by too many variables (topography, temperature and moisture advection, differential

surface heating and the like) to expect any mathematically defined field or "thumbprint" to be unique to a particular weather type. The use of "thumbprints" to describe weather situations was spoken of by Elliott [6] in discouraging terms. For this reason any approach involving the thumbprint technique had been avoided. Now it was hoped that a flexible print could be made, varying in both time and space, to allow for the variations within each weather type while still retaining its uniqueness. In view of the encouraging results of the Cox descriptions, a combination of upper-air flow with certain centers of action and spacial characteristics of the weather on the surface could possibly produce an objective method of classifying weather types.

3. Development

With the upper-level flow indications of the previous investigations and the known features of Elliott's surface weather types it was possible to prepare a dictionary of types based on synoptic parameters. The following is a list of the seven definitive parameters utilized in the dictionary.

P_a	the upper-level (500-mb) flow pattern
P_b	the upper-level (500-mb) ridge location
P_c	the existence of a surface Great Basin Anticyclone
P_d	the existence of a surface Great Basin Anticyclone 24 hours ago
P_e	the existence of a surface Mackenzie River Anticyclone
P_f	the latitude of the 105th meridian crossing of the trajectory of cyclone centers
P_g	the existence of an area of relatively high pressure southwest of California.

The 500-mb flow pattern and the 24-hour time period were determined from the use of the Daily Series Synoptic Weather Maps [11] for data. Refer to figure 3 for geographical orientation.

A numerical code was utilized for describing these parameters in hopes that this would make the dictionary suitable for machine analog or computer work.

Parameter P_a is described as "split" or blocking flow, ridge (meridional) flow and zonal flow. These are designated as "0," "1" or "2," respectively. Particular care was taken to evaluate the space-mean flow in arriving at a flow designation; however, in view of the results thus obtained, the use of a time-mean flow may prove more decisive. Elliott [12] indicates a 2-1/2-day time mean adequately filters out the short-wave systems to determine the long-wave flow. If the Daily Series

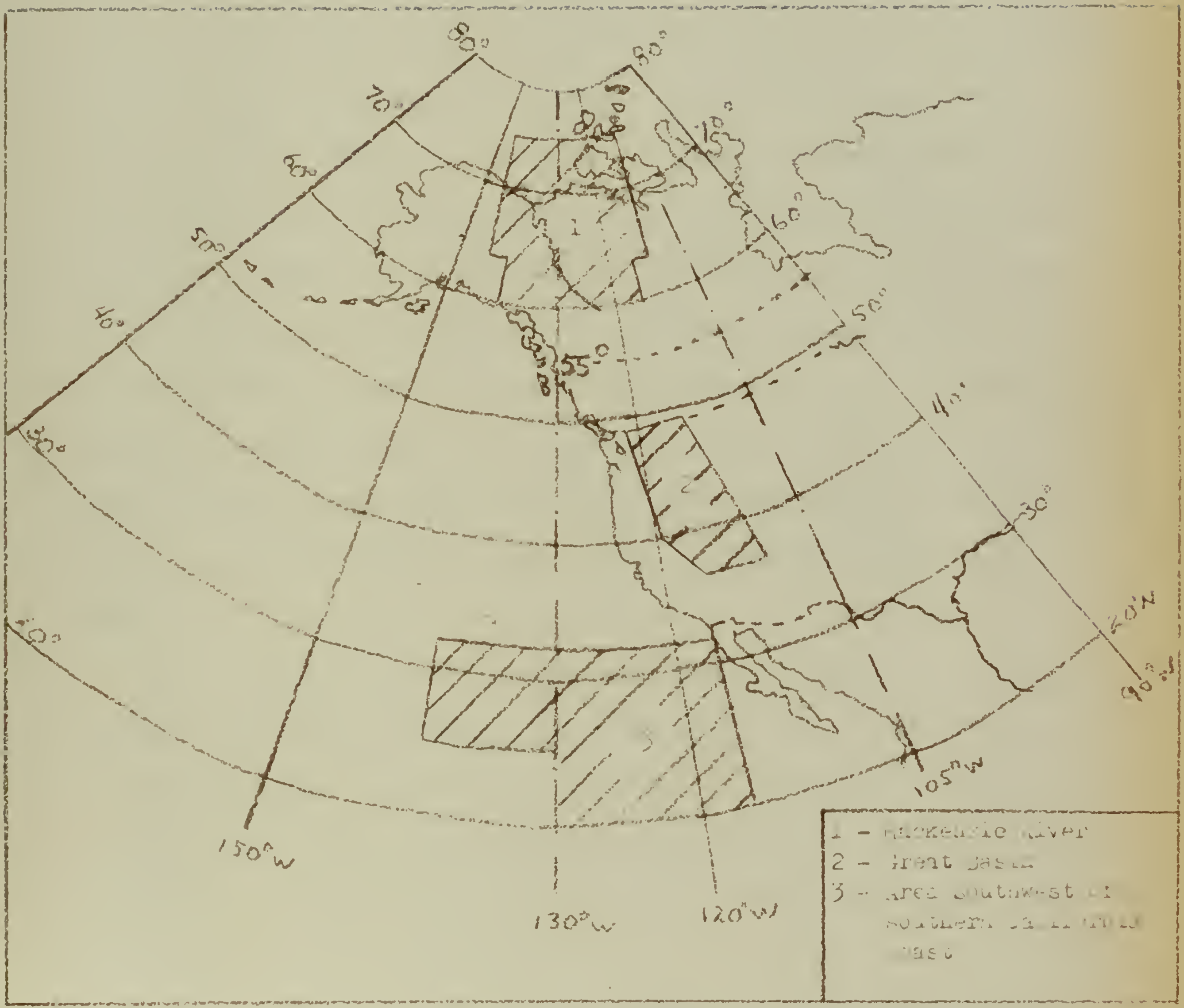

80°
70°
60°
50°
40°
30°
20°
80°
75°
60°
50°
55°
40°
30°
20°N
90°W
105°W
150°W
130°W
120°W
1
2
3
1 - Mackenzie River
2 - Great Basin
3 - Area southwest of southern California coast

Figure 1.

Synoptic Weather Maps are used as a source of data, a three-day time mean is convenient and should be adequate. In general, the upper-level flow between 30°N and 60°N was of interest. A definitely established blocking anticyclone north of 60°N often produces very positive zonal flow south of 60°N. While the predominant feature of the upper-level pattern is split flow, the flow influencing the majority of North America is zonal and is properly coded as zonal. Split flow between these parallels (30°N - 60°N) must be definite, that is, a separation of two or more isohypses such that the main stream of westerlies is clearly split or such that there is a single contour isolation of a cyclone trapped south of a ridge or anticyclone. The ridges must be predominant long-wave ridges with clearly meridional flow to be coded as "1" although the ridge may decrease in size as it travels east, in which latter case continuity governs until another major feature of the upper-level flow enters the area of interest from the west. Minor ridges and troughs can be coded "2."

P_b is coded "1" or "2" if the location of the axis of the ridge near the west coast of North America is either west or east respectively, of the 130th meridian. This may be spoken of as an "offshore" ridge or as an "over-land" ridge, respectively. Although the ridge may be distorted by short-wave systems, the time-mean pattern should smooth these away. The most dominant portion of the ridge axis is of interest even though this portion may be north of 60°N. Minor ridges and troughs may produce deviations in mostly zonal flow to resemble a weak but discernible ridge axis; these must be coded as no ridge, "0."

Since persistence is the rule rather than the exception, once an upper-level flow feature is confirmed as a determining parameter, it should be followed as far as 105°W or until it is replaced by a more dominant

feature from the west before it can be disregarded or discarded. Persistence of several types seems to be a feature or characteristic of those types just as the ephemera of certain other types seems to be a feature or characteristic of them. Years occur when weather falls more readily into the transitory types which persist while the so-called persistent types turn transient. Similar types follow similar types in two-thirds of the cases so that once the dominant upper-level flow feature has been determined it can be expected to be replaced by a similar feature.

The Great Basin Anticyclone should be an area of high pressure enclosed by at least one isobar within the Great Basin region (eastern Washington, Idaho, eastern Oregon, Utah, Nevada and northern Arizona). Sometimes the eastern lobe of the Pacific Anticyclone projects over the Great Basin only to have a trailing front from a cyclone farther north produce a trough and in effect two areas of high pressure where one would normally persist. Occasionally the Basin High is in the process of forming, may be indistinct or is weakening. If the determination of the existence of the anticyclone is necessary to the classification of the type, continue the type existing the day previous.

P_c and P_d are coded "0" for no Great Basin Anticyclone or "1" for a Great Basin Anticyclone. Classifying current weather with available six-hour surface maps may make determination of the true existence of the Great Basin Anticyclone easier than with the 24-hour interval of [11].

The Mackenzie River Anticyclone, P_e, is the term given to high pressure cells having their centers in the general region of the Beaufort Sea-Mackenzie River area of northwest Canada. It is not used to indicate the Alaskan High, but rather the eastern cell of this high-pressure ridge which frequently extends from Siberia or Alaska into Canada. It must be a cell, a closed anticyclone. This is coded "0" for no and "1" for yes.

With regard to P_f if no surface cyclone has passed over 105°W within the past 24 hours, the trajectory of the closest low center should be used (or the center extrapolated to this meridian) in order to obtain the necessary crossing latitude. The center of the cyclone should always be used to determine the trajectory. This parameter (P_f) is coded "0" for centers passing at or north of 55°N; "1" is used for centers passing south of 55°N.

P_g primarily differentiates between the C types and Bn-c types. In the event the Great Basin High determination is indecisive, the existence of an area of higher pressure off the southern California coast, higher than the pressure to the north of this area, indicates a C type.

The coding of these parameters may be combined into a numerical representation or dictionary of weather types. Slants indicate "or"; a dash indicates the parameter is not necessary for determination of the type.

TABLE 2

Dictionary of Weather Types

Type	Bn-c	C_l/C_h*		E_h	Bn-a	Bn-b	B_s	A	D	B	E_l/E_m
Parameter											
P_a	0	0	0	0	1	1	1	1	1	2	2
P_b	1	1	2	2	2	2	2	1	1	0	2
P_c	0/1	0/1	1	0	-	-	-	0	1	-	-
P_d	0/1	1/0	-	-	-	-	-	-	-	-	-
P_e	1	1	0	-	0	1	0	-	-	-	-
P_f	-	-	-	-	0	-	1	-	-	-	-
P_g	0	1	-	-	-	-	-	-	-	-	-

*If the value of the central pressure of the Mackenzie River High is 1040 mb or greater, classify as type C_h. Note two sets of definitive parameters.

The dictionary was applied to 240 cases of winter (1952-3, 1956-7)

weather situations by first evaluating the 500-mb pattern and then taking further definitive features as needed from the surface map. The dictionary classifications were compared with the types as listed in a calendar of types compiled by Elliott [8]. On a strict "agree" or "disagree" basis there were only 83 instances of agreement.

Unfortunately, Elliott's calendar [8] included types which the North American Weather Consultants found necessary in order to describe weather not provided for in the types of 1950 [7]. These were modifications to the existing types to include weather of interest to southern California specifically. Elliott further "back-typed", sometimes allowing as much as three days to pass before assigning a classification to a developed type. Mills [10] also found it necessary to back-type; he differed from Elliott in many instances even when using Elliott's modifications.

Inasmuch as the dictionary classification determines weather types based on current and recently past synoptic situations, neither of the calendars developed by Elliott or Mills was considered a suitable standard. A comparison is presented with the Elliott-Mills calendars, but no attempt is made to evaluate this system with theirs. The comparison is held not to be significant except in that it points out the possibility that the persistence of regularities in weather phenomena is less than is actually supposed. Table 3 contains this comparison.

A closer look at types classified as being the same by Elliott and Mills during the period shown in Table 3 indicates that while some surface patterns do have some particular singularity in the 500-mb flow over them, this particular feature appeared free to move within the area of interest and at times become difficult to distinguish. Table 4 is a summarization of this closer look. The flow indications for the various meridians are the same as described by Cox [4]; the arrows are for the

Date	November 1952			December 1952			January 1953			February 1953		
1	D	B	Bn-a	C_1	D	B	B_s	Bn-b	Bn-a	E_1	B_s	B_s
2	Bn-a	Bn-b	"	B	"	"	Bn-b	"	"	"	"	"
3	"	"	"	"	"	"	"	E_m	E_m	"	"	"
4	C_1	C_1	C_1	E_1	"	"	"	"	"	"	"	"
5	"	"	"	"	B	"	C_h	"	"	"	Bn-c	"
6	"	"	"	B	"	"	"	"	"	"	"	B
7	"	"	"	"	"	"	"	"	"	B	"	"
8	Bn-a	Bn-a	Bn-a	"	"	"	Bn-b	B_s	B_s	C_1	"	Bn-c
9	"	"	"	E_1	"	"	"	"	"	"	"	"
10	"	"	"	"	"	"	"	"	"	"	"	"
11	"	B	B	B	"	"	B_s	E_m	E_m	"	"	"
12	"	"	"	Bn-a	Bn-a	Bn-a	B	"	"	"	Bn-b	Bn-a
13	E_1	A	"	"	"	"	"	"	"	"	"	"
14	"	"	"	"	"	"	"	"	"	B_s	B	B
15	A	Bn-b	Bn-a	B_s	"	"	Bn-b	B	B	B	"	"
16	C_1	"	"	C_1	C_h	C_h	B	"	"	"	Bn-c	"
17	D	"	"	"	"	"	"	"	"	"	"	"
18	Bn-a	Bn-c	Bn-c	"	E_m	"	"	"	"	Bn-c	"	Bn-c
19	"	"	"	"	"	"	"	E_m	"	"	"	"
20	"	"	"	"	Bn-a	C_1	C_1	"	"	"	"	"
21	"	"	"	"	"	"	"	Bn-b	"	Bn-a	"	"
22	"	"	"	A	"	"	"	"	Bn-a	C_1	"	"
23	Bn-c	"	"	Bn-b	"	"	Bn-a	D	"	"	Bn-b	"
24	"	"	"	C_1	B_s	"	Bn-b	"	D	"	"	"
25	"	B	"	"	"	B	A	"	"	"	"	"
26	"	"	"	"	E_m	"	D	"	"	"	A	"
27	"	A	A	"	"	"	"	"	"	"	"	"
28	C_1	"	"	"	B	"	Bn-b	B_s	B_s	"	"	A
29	"	"	D	"	"	"	B	"	"			
30	"	D	"	"	"	"	"	"	"			
31				"	Bn-b	Bn-a	E_1	"	"			

KEY

Date	November 1952		
1	Clark	Elliott [8]	Mills [10]
2	"	"	"
3	"	"	"

TABLE 3

convenience of the reader not having access to a Cox Flow Direction Indicator.

Of special interest in Table 4 are the variations from the dictionary flow/ridge standards in the types of 11 November, 18-24 November, 5-7 December and 3-7 January. The last is worthy of particular attention in that a very strong high latitude block dominated the west coast of Canada producing first meridional and then zonal flow at 40°N over the western United States yet both Elliott and Mills classify it as a zonal type E_m for the entire period.

The flow directions across the various meridians indicate the locations of ridges, troughs and centers of action at 40°N. From these it is apparent that these features move or appear to move either east or west within 40° of 135°W. The ridge in type C_1 of 4-7 November seems to move from east of 130°W to west of this meridian then disappear. Type D of 24-27 January has a similar confused history. The Bn-c of 18-24 November was marked by being displaced well over the coast with a surface Great Basin High in the same position as a C type. If the upper-level flow references had been similarly moved to the east, there would not have been the differences between the flow descriptions for this type.

All these differences in the upper-air flow over the actual types as compared to the dictionary flow emphasize the lack of strength in the stand that the upper-air flow determines the surface weather type. However, the knowledge that a particular surface situation is associated frequently with a typical upper-air flow configuration is still valid and may help in the final determination of a type. The emphasis should now shift from first defining the upper levels to the initial perusal of the surface for a possible classification then confirming it with the 500-mb flow. This may make the application of the dictionary an objective method of classifying types.

(P_a/P_b) Flow at 40°N

Date	Type	Flow/	Mixing	170°W	150°W	130°W	110°W	90°W
11-2-52	Bn-b	1	2	7 ↘	5 ↗	6 →	7 ↘	6 →
3	"	1	2	6 →	7 ↘	5 ↗	8 ↓	8 ↓
4	C_1	0	1	6 →	6 →	5 ↗	9 ○	7 ↘
5	"	0	1	6 →	5 ↗	8 ↓	6 →	7 ↘
6	"	0	1	7 ↘	5 ↗	8 ↓	6 →	7 ↘
7	"	0	1	6 →	6 →	8 ↓	6 →	7 ↘
8	Bn-a	1	2	6 →	6 →	5 ↗	7 ↘	6 →
9	"	1	2	5 →	6 →	5 ↗	8 ↓	6 →
10	"	1	2	6 →	6 →	6 →	8 ↓	6 →
11	B	1	2	6 →	6 →	5 ↗	6 →	7 ↘
12	"	2	2	6 →	6 →	6 →	5 ↗	6 →
18	Bn-c	1	2	6 →	6 →	9 ○	8 ↓	5 ↗
19	"	1	2	6 —	6 →	9 ○	8 ↓	6 →
20	"	1	1	6 →	5 ↗	1 ↙	5 ↗	8 ↓
21	"	1	1	7 ↘	5 ↗	1 ↙	6 →	8 ↓
22	"	1	2	6 →	5 ↗	8 ↓	6 →	6 —
23	"	1	1	5 ↗	5 ↗	8 ↓	8 ↓	6 —
24	"	1	1	6 →	5 ↗	8 ↓	8 ↓	5 ↗
27	A	1	1	6 →	6 →	7 ↘	6 →	6 →
28	"	1	1	5 ↗	6 →	7 ↘	8 ↓	6 →
12-5-52	B	1	2	6 →	6 →	7 ↘	5 ↗	7 ↘
6	"	2	2	6 →	6 →	7 ↘	6 →	6 →
7	"	2	2	6 →	6 →	6 →	6	6 →
8	"	2	0	6 →	6 →	6 →	6 →	6 →
1-3-53	E	1	2	7 ↘	5 ↗	5 ↗	7 ↘	7 ↘
4	"	1	1	6 →	5 ↗	5 ↗	7 ↘	7 ↘
5	"	0	1	6 →	6 →	4 ↑	7 ↘	7 ↘
6	"	0	1	6 →	6 →	6 →	6 →	6 →
7	"	0	1	7 ↘	5 ↗	6 →	6 →	6 →
8	B	1	2	7 ↘	7 ↘	5 ↗	7 ↘	7 ↘
9	"	1	2	6 →	5 ↖	5 ↗	6 →	8 ↓
10	"	1	2	1 ↙	1 ↙	5 ↗	6 →	7 ↘
24	D	1	1	9 ○	7 ↘	5 ↗	6 →	7 ↘
25	"	1	1	5 ↗	7 ↗	6 →	6 →	7 ↘
26	"	1	1	3 ←	4 ↑	6 →	6 →	6 →
27	"	1	1	6 →	5 ↗	6 →	7 ↘	6 →

Table 4.

4. Objectivity

It became immediately apparent that the dictionary was not sufficient in itself as an objective technique for classifying surface weather types. P_a and P_b were the most difficult to classify objectively, thus various methods of facilitating their classification were investigated. These follow.

Vernon's [18] pressure-gradient technique modified for a grid of nine actual reporting stations was first applied to 1-24 January 1953 to determine the location of the ridge axis at 500 mb (P_b). The stations were centered about Salem, Oregon. Height differences were taken between stations on the same parallel with each other, averaged and compared for west of the centerline to east of the centerline. The decision as to the location of the area of greater heights and the magnitude of the difference indicated the ridge axis location with respect to 130°W. The stations were Kodiak (350), ocean station PAPA, ocean station NOVEMBER, Fort Nelson (945), Tatoose Island (798), San Diego (290), Fort Smith (934), Glascow (768) and El Paso (270). This determination was offset slightly east of south, paralleling the west coast of North America, and was not sufficiently definitive.

A three-day time-mean flow was taken for 500-mb flow across 130°W with readings every five degrees of latitude from 60°N to 30°N for the period 1 November 1952 to 28 February 1953. This was not decisive. The three-day time-mean profile was moved west to 145°W with no improvement in indications.

The west-east profile as used in Table 4 for the flow at 40°N may prove the necessary objective method of arriving at the determination of P_a and P_b; however, time no longer permitted any further development of this approach. It is recommended that a three-day mean again be applied to this flow if it is further investigated.

5. Conclusions

During the course of this investigation it became more and more obvious that there are general upper-air flow patterns associated with surface weather types. With the subjective classification of types now in use it is vital that an objective technique be devised to standardize typing for synoptic climatology as well as analog research.

The use of "meridional" and "zonal' flow is not sufficiently exact for the description of the flow over the various existing surface types. A three-way description as "split" or "blocking," "ridge" (meridional) or "zonal" flow is more adequate.

If there is a particular upper-air flow pattern for the various surface types, then this flow pattern must not be ignored or disregarded when classifying a weather type. Because of this, major discrepancies may have occurred in both Elliott's and Mills' calendars.

The dictionary of weather types, Table 2, can aid in the subjective identification of Elliott's surface weather types by calling the attention of the classifier to the pertinent features of the synoptic map being classified.

The results of the use of the dictionary may indicate that some presently recognized weather type is in actuality only a phase of another more persistent type and that the regularities in weather phenomena are of either greater or less persistence than supposed. That is, the three-day cycle of Elliott may indeed be six or nine days with three-day interim or change periods.

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